Statistics Examples from Kennedy Space Center and Cape Canaveral Air Force Station

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Agenda

- Overview
- Why knowing statistics is valuable
- Work Examples in Meteorology and Engineering
  - General Statistics and Statistical Analysis
  - Design of Experiments (DOE)
  - Monte Carlo Simulation

Statistical Analysis

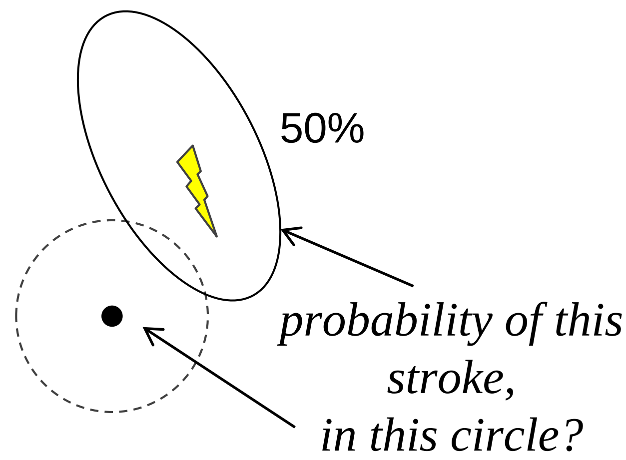
Lightning Probability in a Circle

Position uncertainty of the lightning stroke relative to the area of interest is described by a bivariate Gaussian probability density function (pdf) :

$$f_2(x,z) = \frac{1}{2\pi\sigma_x\sigma_z\sqrt{1-\rho_{xz}^2}} e^{-\left[\left(\frac{x}{\sigma_x}\right)^2 - 2\rho_{xz}\left(\frac{x}{\sigma_x}\right)\left(\frac{z}{\sigma_z}\right) + \left(\frac{z}{\sigma_z}\right)^2\right] / 2\left(1-\rho_{xz}^2\right)}$$

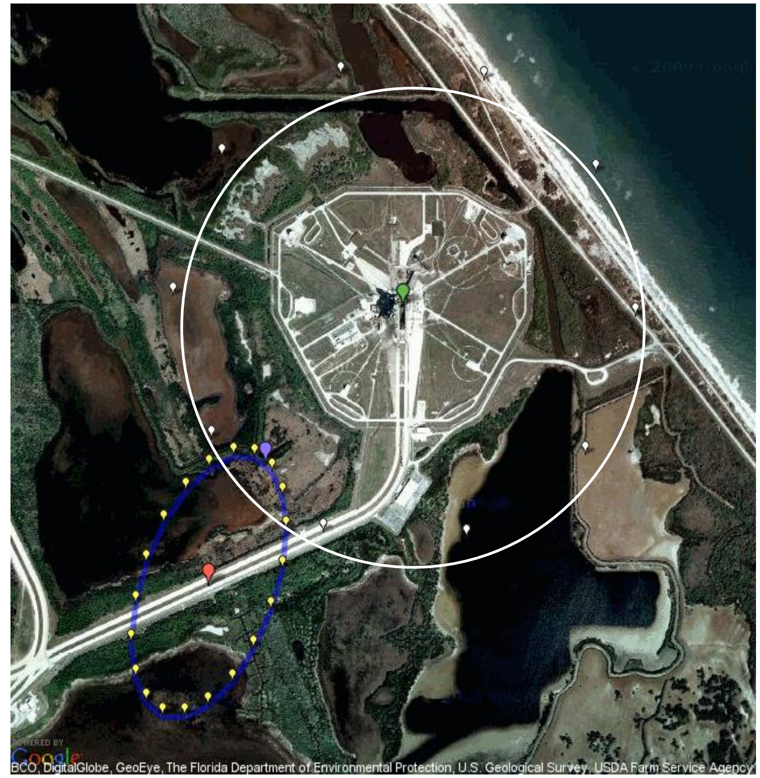
Probability of stroke being in area of interest is given by the two-dimensional integral, where A is the area within the perimeter around the point of interest.

$$P = \iint_A f_2(x,z)\,dxdz$$



Lightning Probability in a Circle

- No known solution to the above integral when the two standard deviations σ_x and σ_z are not equal.
- The solution is based on a numerical algorithm that integrates the area of the ellipse over the area of the circle.
- Algorithm from "Spacecraft Collision Probability", by Dr. F. Kenneth Chan.



Probability = 0.7%

Design of Experiments (DOE) Example

Design of Experiments (DOE) Example

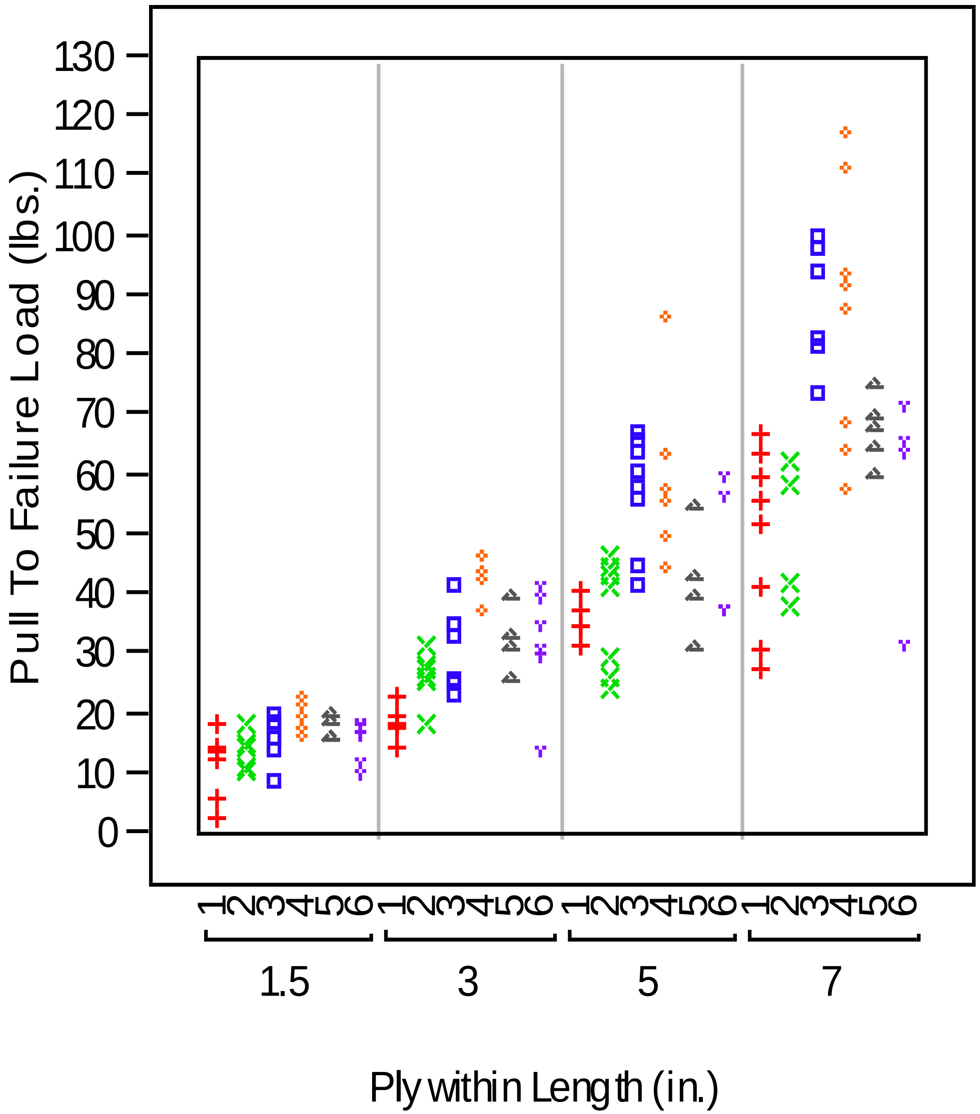
Qualification Test of Process Enhancements

– 144 gap fillers distributed as follows

Factors	Levels
Technicians	6 levels - randomly selected from population of technicians with gap filler cert
Inspectors	2 levels- randomly selected from population of TPS quality inspectors
Fill type	2 levels– complete or nominal
Lengths	4 levels – 1.5”, 3”, 5”, and 7”
* Plys/flat panel	3 levels – 1, 3, and 4 ply
* Plys/curved panel	3 levels – 2, 5, and 6 ply

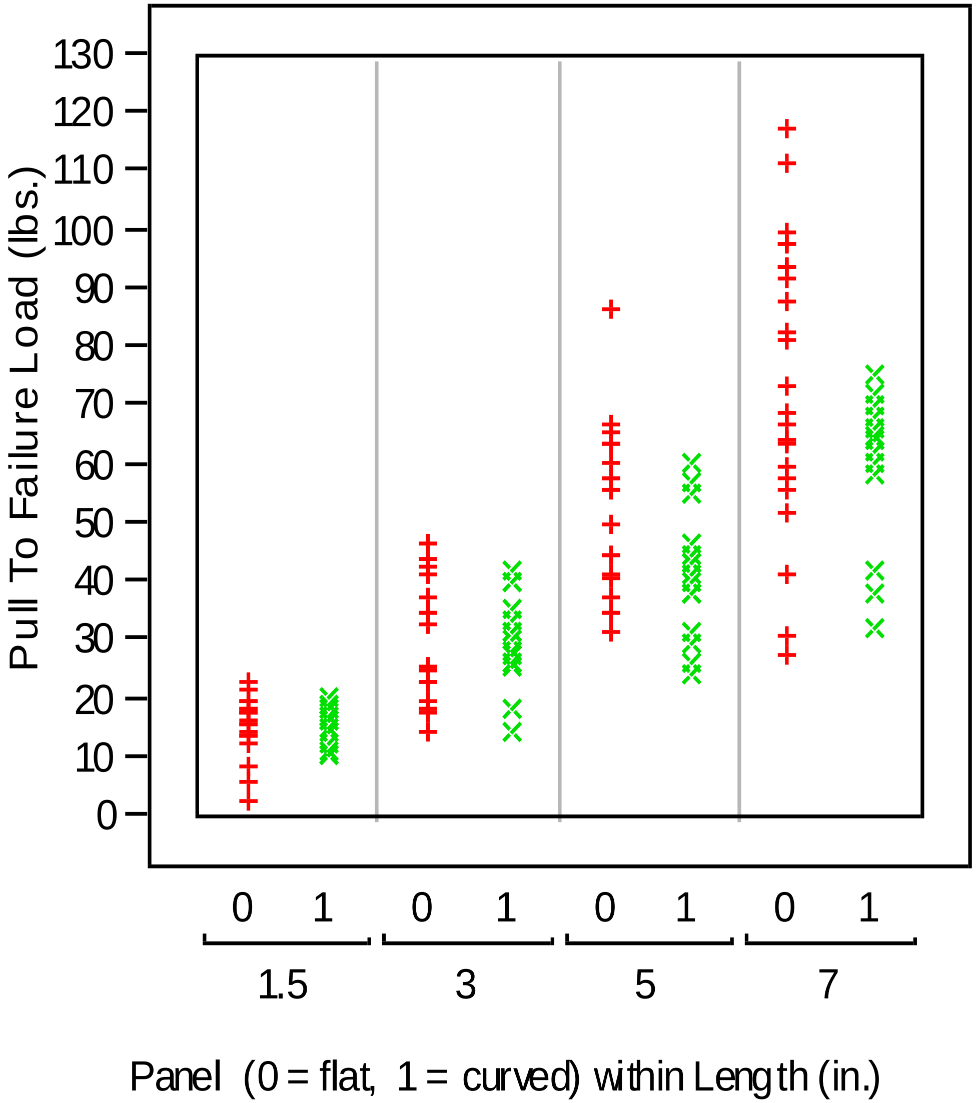
* These factors are not independent because MLGD impact testing (flat) panels that were already available for testing with no work required. Unfortunately, the gaps between tiles on these panels would only accommodate a thickness of no greater than a 4-ply gap filler.

Design of Experiments (DOE) Example



The variability of failure pull load with ply and length. It is easy to see an upward trend of bond strength with length and ply. Different colors denote different plies.

Design of Experiments (DOE) Example

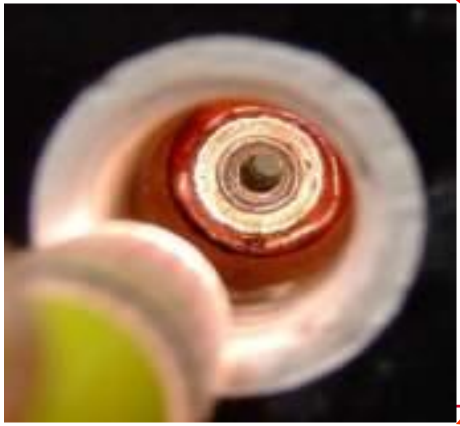


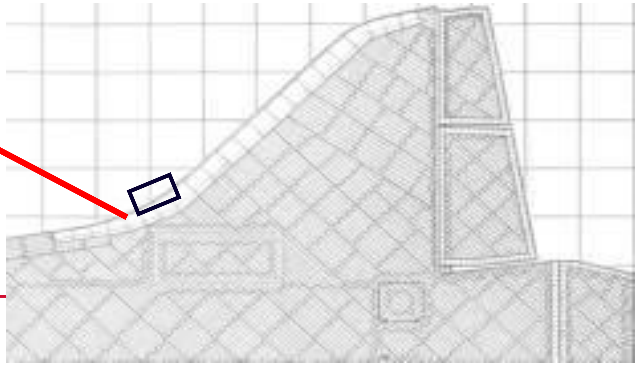
The variability of failure pull load with length and panel type. It is easy to see an upward trend of bond strength with length and panel type. Different colors denote different panel types.

Monte Carlo Example - LESS Carrier Panel Issue

- **Observation:**
  - **During Lower LESS access carrier panel installation on OV-103, a washer was noted under a fastener in two panel locations**
    - **Per design, fastener is countersunk with no washer required**
- **Concerns:**
  - **Condition could exist on OV-104/OV-105, potentially leading to:**
    - **Fastener failure**
    - **Panel deflection**
    - **Panel lack of retention**

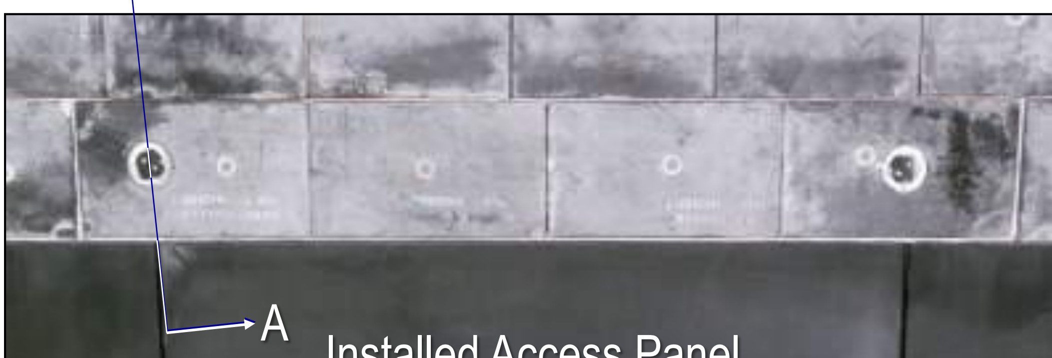
Monte Carlo simulation was used to calculate the probability of this concern.

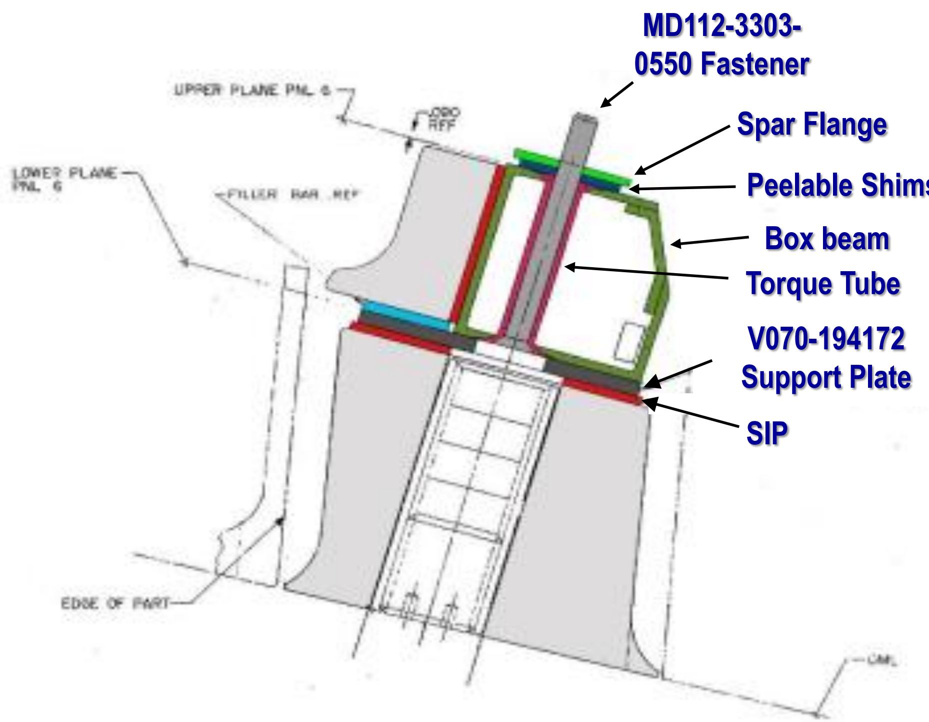




Panel 6R after washer removed

Monte Carlo Example - LESS Carrier Panel Issue



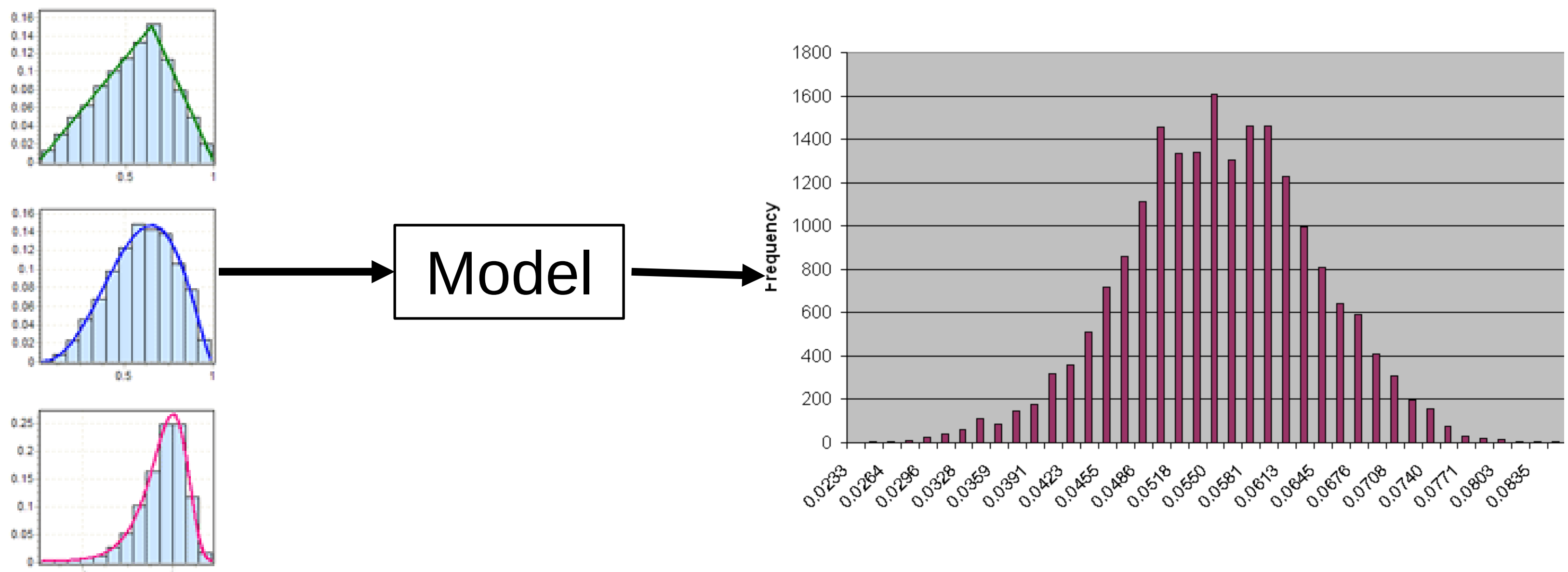


View A-A

Background for Monte Carlo Simulation

When to use it

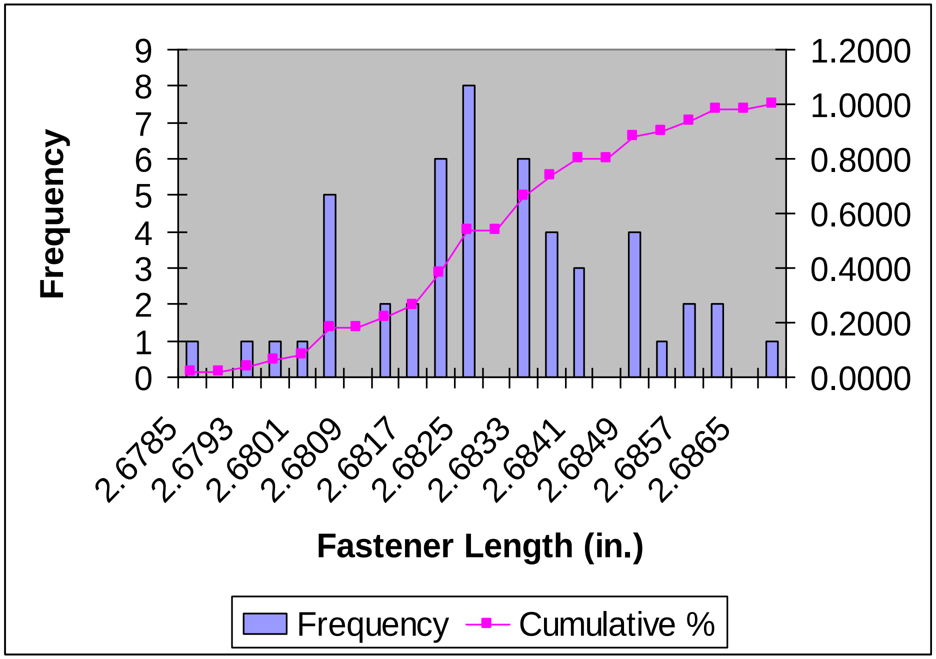
– When analytical methods meant to imitate a real-life system are too difficult, mathematical complex, time-consuming, costly, or dangerous to reproduce.

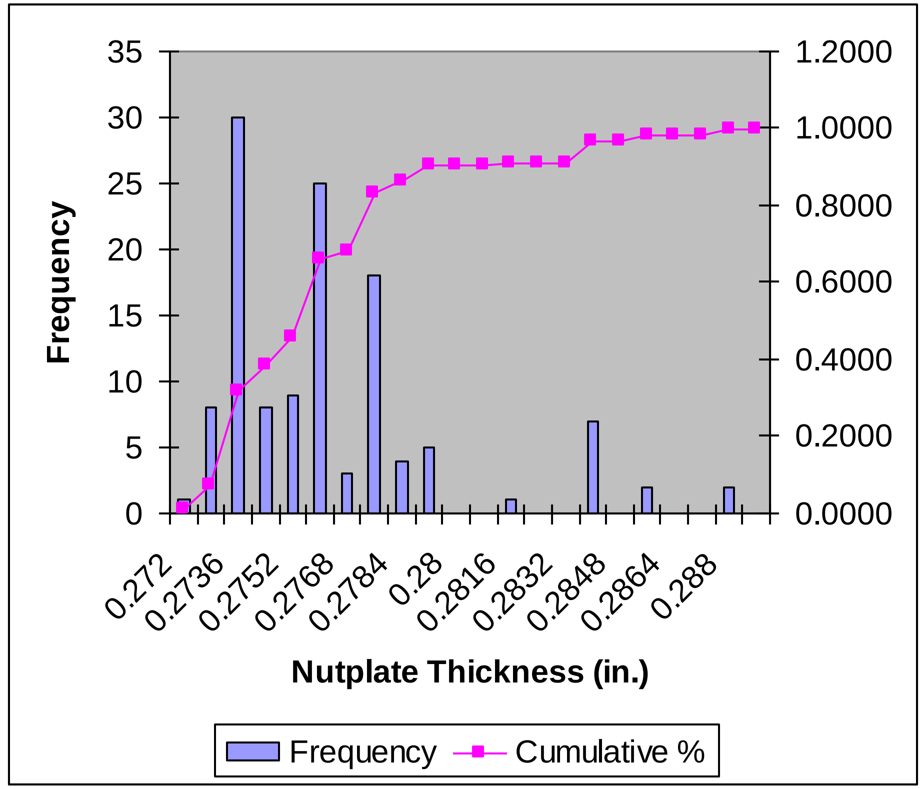


Inputs

Output

Monte Carlo Example – Input distributions





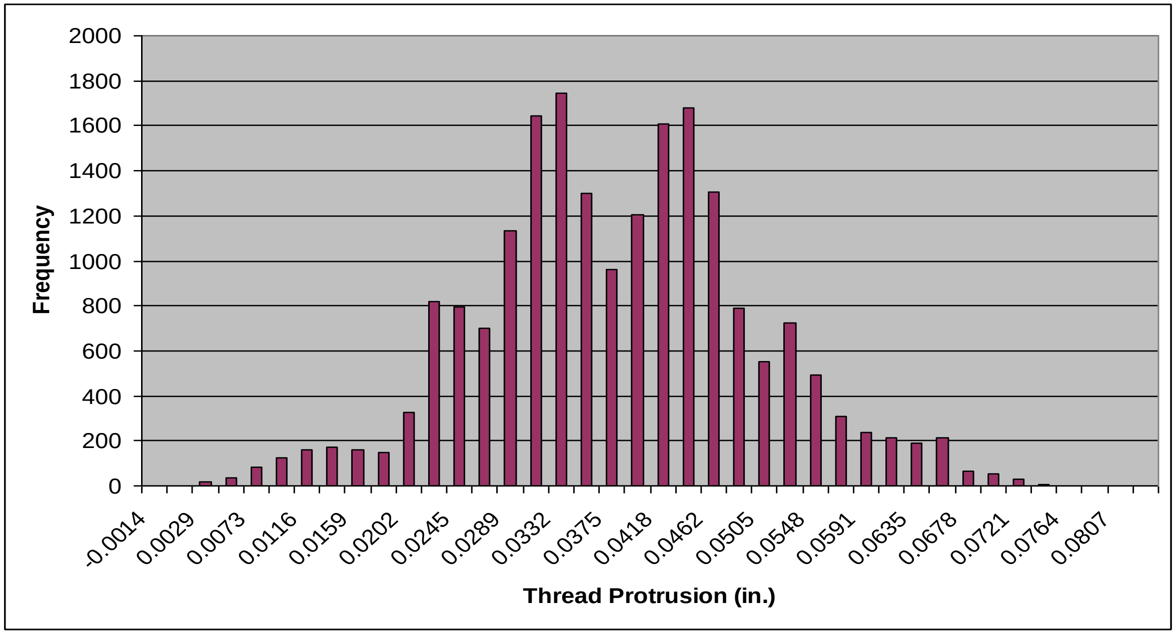
These distributions are from fasteners and nutplates actually measured from Logistics' stock.

Monte Carlo Example

Thread Protrusion (in.)	Frequency
-0.0014	2
0.0008	1
0.0029	18
0.0051	34
0.0073	82
0.0094	124
0.0116	163
0.0137	171
0.0159	159
0.0181	148
0.0202	328
0.0224	818
0.0245	794
0.0267	701
0.0289	1131
0.0310	1645
0.0332	1745
0.0354	1301
0.0375	961
0.0397	1205
0.0418	1610
0.0440	1677
0.0462	1307
0.0483	790
0.0505	553
0.0526	723
0.0548	490
0.0570	307
0.0591	238
0.0613	211
0.0635	191
0.0656	215
0.0678	67
0.0699	51
0.0721	27
0.0743	7
0.0764	2
0.0786	2
0.0807	0
0.0829	1

Assumptions: **All variables normally distributed except nutplate height and bolt length are truncated normals**

Variable	Mean	Std. Dev.	
box beam	2.000	0.007	
peelable shims	0.107		fixed
spar fitting	0.100	0.003	
nutplate	0.292	0.006	
washer thickness	0.075		fixed
head protrusion	0.070		fixed
fastener length	2.680	0.008	



Probability Thread Protrusion >= X in.	X (in.)
Close to 100%	-0.0035
95%	0.0189
90%	0.0221
85%	0.0249
80%	0.0278
75%	0.0293
70%	0.0307
65%	0.0319
60%	0.0331
55%	0.0347
Median = 50%	0.0368
45%	0.0388
40%	0.0404
35%	0.0417
30%	0.0428
25%	0.0443
20%	0.0459
15%	0.0486
10%	0.0519
5%	0.0571
1%	0.0649
Close to 0%	0.0829

Average	0.0369

This case showed it was possible to have no bolt protrusion out of the nutplate 2 times out of 20,000 runs.